

The University of Chicago

INDIVIDUAL DIFFERENCES IN LEARN-
ING TO REPRODUCE FORMS:
A STUDY IN ATTENTION

A PART OF A DISSERTATION SUBMITTED
TO THE FACULTY OF THE DIVISION OF
THE SOCIAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF EDUCATION

1940

By
LEE J. CRONBACH

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INDIVIDUAL DIFFERENCES IN LEARNING TO REPRODUCE FORMS: A STUDY IN ATTENTION

By LEE J. CRONBACH, State College of Washington

In the learning of handwriting, shorthand, art, and other subjects, the ability to learn and reproduce complex forms is important. The nature of such learning has been studied in many investigations, of which the most complete are those of Judd and Cowling,¹ Tripp,² Binet,³ Stratton,⁴ Piéron,⁵ Albein,⁶ and Kuhlmann.⁷ Many of these studies have been based on extremely small groups of subjects.

Judd and Cowling analyzed drawings made by 8 Ss, to determine how a percept develops. Each figure was reproduced by S after successive 10-sec. exposures. Judd and Cowling assumed that changes in the reproduction from trial to trial reflected S's distribution of attention on each trial. Thus, a gain at any point implied that S had studied that point, and a loss was taken to mean a withdrawal of attention from that point.

The present study is a repetition of the experiment by Judd and Cowling, designed to extend its validity and to check their assumption. Photographic eye-movement records were made during the study of three diagrams; comparison of these records with the reproductions makes it possible to determine more validly the methods of study.

Few experiments have studied eye-movements during the learning of form. Rubin tested the hypothesis that sensations of tracing a figure mentally during study lead to eye-muscle sensations which can be recalled.⁸ He concluded that "what we had

* Accepted for publication June 30, 1940. This study is condensed from a doctorate dissertation from the Department of Education, University of Chicago. The author is indebted to Professor G. T. Buswell for guidance. A preliminary experiment was conducted at the University of California at Berkeley, under the supervision of Professor L. C. Gilbert.

¹ C. H. Judd and D. J. Cowling, Studies in perceptual development, *Psychol. Monog.*, 8, 1907, (no. 34), 349-369.

² M. G. Tripp, Perceptual learning at different grade levels, Univ. of Chicago, 1926 (unpublished thesis).

³ Alfred Binet, Attention et adaptation, *Année Psychol.*, 6, 1899, 248-404.

⁴ G. M. Stratton, *Experimental Psychology and Its Bearing Upon Culture*, 1908, 176 ff.

⁵ Henri Piéron, Recherches comparatives sur la mémoire des formes et celle des chiffres, *Année Psychol.*, 21, 1920, 119-148.

⁶ Gustav Albein, Der Anteil der nachkonstruierenden Tätigkeit des Auges und der Apperception an dem Behalten und der Wiedergabe einfacher Formen, *Zsch. f. exper. Pädagogik*, 5, 1907, 133-156; 6, 1908, 1-48; and suppl. to Vol. 6, 1907.

⁷ F. Kuhlmann, On the analysis of the memory consciousness: a study in the mental imagery and memory of meaningless visual forms, *Psychol. Rev.*, 13, 1906, 316-348.

⁸ Edgar Rubin, *Visuell wahrgenommene Figuren*, 1921, 153 ff.

hitherto supposed, that these sensations are connected with the movements of the eyes, is proven false, and all assertions about eye movements which rest upon these sensations are undemonstrable." Stratton⁹ and Buswell¹⁰ have photographed the eyes while *S* looked at forms or traced them visually. Brandt photographed eye-movements while *S* studied a symmetrical pattern with intent to reproduce.¹¹ He was primarily interested in the attention-values of parts of the figure, and disregarded relations between study methods and reproductions. Guilford and Hackman also used eye-movement records to study the attention-values of stimuli.¹² These studies are agreed that *S* may attend to a point in the figure without fixating it foveally. It appears reasonable, however, to assume that any shift of fixation during study is toward a position of greater attractiveness, and that the eye-movement record gives a close approximation to the point given attention.

The specific purpose of the present study is to investigate the following questions: (1) Is the assumption of Judd and Cowling valid; namely, that the distribution of attention is indicated by *S*'s reproduction? (2) What characteristics distinguish the study patterns of good and poor learners? (3) What changes in study pattern accompany a change in the difficulty of the figure studied? (4) Are individual differences in ability to learn figures constant from figure to figure? (5) How does such ability correlate with mental abilities measured by American Council Psychological Examination? (6) Are the 'types' of study defined by Judd and Cowling, those defined by Albein, Katz, and others, or those defined by Wulf, characteristic of individuals throughout their study of several figures?

Seven of Judd and Cowling's *Ss* drew the form as a whole on the first trial, and refined details in later reproductions. One *S* drew only part of the figure on the first trial, attending to details. He augmented this drawing piecemeal on further trials. These differences were thought by Judd and Cowling to indicate 'whole' and 'part' procedures in studying, respectively. Albein, Katz,¹³ and other workers classified their *Ss* as 'objective' or 'subjective.' 'Objective' learners formed visual impressions, using no associations during study, while 'subjective' learners always relied on associations in studying nonsense forms. While Albein noted that some persons are between these extreme positions in behavior, Katz and his followers have been inclined to view the classification as dichotomous. Wulf,¹⁴ on the other hand, denied the validity of Katz' types, and classified learners as 'isolative' or 'comprehensive,' depending on the type of association they employed. Wulf held that every learner

⁹ G. M. Stratton, Eye-movements and the aesthetics of visual form, *Philos. Stud.*, 20, 1902, 336-359.

¹⁰ G. T. Buswell, *How People Look at Pictures*, 1935, 1-198.

¹¹ H. F. Brandt, Ocular patterns and their psychological implications, this JOURNAL, 53, 1940, 260-268.

¹² J. P. Guilford and R. B. Hackman, Varieties and levels of clearness correlated with eye-movements, this JOURNAL, 48, 1936, 371-388.

¹³ David Katz, Über individuelle Verschiedenheiten bei der Auffassung von Figuren, *Zsch. f. Psychol.*, 45, 1913, 161-180.

¹⁴ F. Wulf, Über die Veränderung von Vorstellungen, *Psychol. Forsch.*, 1, 1922, 33-373.

uses associations at times during learning. If any of these three trait descriptions is to be accepted, it becomes necessary to demonstrate (1) that such differences do exist, and (2) that learners belonging to a given type on one figure will belong to the same type on other figures.

METHOD

In repeating the Judd-Cowling experiment, the following methodological changes were made: (1) the number of Ss was increased to 118; (2) the stimulus-objects were presented to Ss in groups as well as individually; (3) high school pupils instead of graduate students were used as Ss; and (4) stimulus-figures of varying, instead of uniform, difficulty were employed. The procedure in this investigation falls into two parts: (I) a group experiment with an unselected group of Ss; and

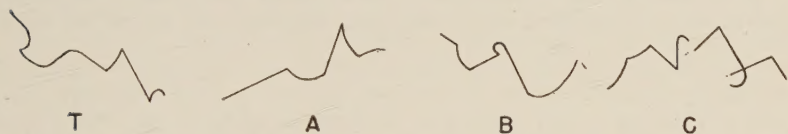


FIG. 1. STIMULUS-FIGURES USED IN THE GROUP EXPERIMENTS

(II) an individual test of selected good and poor learners whose eye-movements were photographed during the study.

(I) *Group experiment.* (1) *Subjects.* All members of the ninth and tenth grades of University High School, Chicago, Illinois, present at the time of the test served as Ss. There were 40 boys and 78 girls, 118 in all.

(2) *Stimulus-figures.* Four line diagrams, T, A, B, and C, were used as the stimulus-figures (see Fig. 1). They were designed to give a minimum of regularity or pattern and to provide a range of difficulty. They were also designed so that they could be drawn with a minimum of left-to-right movement or doubling back; this made the horizontal eye-movement records more interpretable and increased the resemblance to shorthand symbols. Diagram T was used as a specimen while instructing the Ss. Each diagram was drawn on groundglass, and presented by projection on the front wall of a semi-darkened room.

(3) *Procedure.* Directions were as follows:

We are investigating the methods of study you use in learning. After I say 'Ready,' you will be shown a figure like this on the screen for a brief interval. [T projected on screen.] When I turn off the light, draw it as well as you can on the piece of paper you have been given. Keep as near the correct shape of the figure as possible, drawing as much as you can remember. Study carefully, paying attention to the size of angles, to whether the lines are straight or curved, and to how their lengths compare with each other.

After you have completed your drawing, you will be given another chance to study the figure. Then you will draw it on another of your sheets of paper. Enough trials will be made so that most of you will be able to reproduce the figure perfectly.

Before the test, every S was given 30 small sheets of paper. The stimulus-figures were presented in the order of difficulty—A, B, C—for 7, 10, and 10 trials respectively. Every exposure was of 10-sec. duration.

(4) *Scoring.* The following arbitrary rules (adapted from Judd and Cowling) were used in scoring. Each of the following was scored as one gross error.

- (a) An added line, or closure of a gap present in model figure.
- (b) A straight line shown as curved, or a curved line shown as straight.
- (c) A convex curve shown as concave, or vice versa.
- (d) A line over one and one-half times its proper size, as compared to adjacent lines; or a line less than two-thirds its proper size, as compared to adjacent lines.
- (e) An angle showing an absolute error of 60° from its proper size, or a corner rounded, or an angle added to the model figure.
- (f) A curve having a radius of curvature over twice its proper size, or under half its proper size, as compared to its length.
- (g) In a discontinuous figure, a marked failure to orient separate sections properly with relation to each other.

An omission of a line, or discontinuity not present in original figure, was scored as three errors, to provide a more linear scale. Drawings with one or two errors

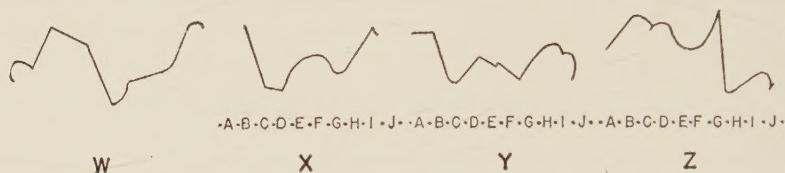


FIG. 2. STIMULUS-FIGURES USED IN THE INDIVIDUAL EXPERIMENTS

Dots beneath diagrams X, Y, and Z indicate how each diagram was divided into tenths; the letters between the dots refer to the areas.

are nearly perfect. It cannot be assumed that intervals on the scale are equal, and, of course, a scoring which neglects structure relations cannot be completely satisfactory.

The total score on each figure was the sum of scores on all trials. The total score on the group test was obtained by the formula $3A + 2B + C$, which approximately equalized the contribution of the tests to the total variance.

E scored the drawings by transparency. A test of the reliability of scoring was made by rescored a sample of the drawings after a 2-wk. interval. *E* rescored drawings of 40 Ss on each of 9 trials; the correlations between the two sets of scores on each trial ranged from 0.69 to 0.92, averaging 0.86.

(II) *Individual experiment.* (1) *Subjects.* On the basis of group test scores, 24 good and 22 poor learners were selected for retesting. In selecting the Ss, preference was given to those having scores that deviated consistently on all figures. The good group contained 11 boys, 13 girls; the poor group, 9 boys and 13 girls. The mean scores of the groups on Diagrams A, B, and C were respectively for the good group, 15.5, 26.7, and 57.2, and for the poor group, 34.9, 69.2, and 127.7.

(2) *Stimulus-figures.* Four new stimulus-figures, W, X, Y, and Z (Fig. 2), were prepared as before and photographed on 35-mm. films.

(3) *Procedure.* About 2 mo. after the group test, the Ss were summoned individually for retesting. The equipment consisted of an eye-movement camera, stool, table, and a mounted still-film projector. The projector, placed about a foot above the camera, cast a white-on-black image $10\frac{1}{2}$ by $8\frac{1}{4}$ in. on the buff-colored wall about

39 in. in front of S's eyes. The wall was unmarked except for two black dots at the upper corners of the area where the image was to appear. These dots were used for pre-fixation. S was informed that his eye movements were to be photographed to obtain a record of his study habits. He was not told, however, that he had been selected because of atypical performance on the group test; but was, instead, let to believe that a random sample of the class was to be retested.

S was seated on the stool, adjusted to the camera, which was focussed on his right eye. Trials on W were then made without the use of film. After several trials with stimulus-figure W, S was asked to copy it while it was exposed. Series of trials on X, Y, and Z were then made, during which the right eye was photographed. Procedure for each trial included focussing of camera, instruction to fixate the left dot, instruction to fixate the right dot, exposure and instruction to study, end of exposure and withdrawal of S from camera, and reproduction of figure. Exposure lasted 10 sec.

S was allowed a maximum of 8 trials on stimulus-figure X, 10 each on Y and Z. If, in the opinion of E, two consecutive drawings showed no error, the series was terminated at that point to save time and to reduce boredom. This judgment was made rapidly and somewhat subjectively; some series were terminated too early as a result.

At the end of the Z-series, S was informally interviewed. He was first encouraged to describe his methods of study, then to answer the following questions. (a) Did you study the figure as a whole, or part by part? (b) Did you attempt to trace the figure in the air while studying? (c) Did you gain assistance from noticing that the diagram or any part of it resembled any object, letter, or number?

Every diagram was shown to S, who was asked to point out associations. Use of kinesthesia was also determined by E, who observed frequently during study whether tracing movements appeared.

(4) *Scoring.* Drawings were scored as before. The formula $2X + Y + Z$ was used for the total score. In any case where the series had been ended even though the last reproduction contained errors, the total score for the figure was obtained by assuming that S would have made the same number of errors in each further trial if more had been allowed.

(5) *Plotting of films.* All films were plotted by projection, using the fixations on the dots before study and the head record to determine the location of fixations. Each fixation-record on the film appeared as a dotted line, each dot representing 1/30 sec. After the initial plotting, all records were rapidly replotted, as a check. Records for trials in which the plotting was uncertain were discarded.

When S is looking at a section of the stimulus-figure, what he sees varies little if he shifts his fixation-point a short distance. On the assumption that such movements are not significant, consecutive fixations falling within $\frac{1}{2}$ cm. of each other on the plotting sheet (equivalent to 0.30 in. on the figure projected on the wall or to a shift of visual angle of $0^{\circ} 26'$) were counted as a single fixation. This assumption tends to increase the average duration of fixations.

RESULTS

(1) *Learning curves.* The mean score on each stimulus-figure, for every trial, is shown in Table I. It is evident that development was gradual and

that the relative difficulty of the stimulus-figures was the same on all trials. Group learning curves were obtained by plotting each score as a percentage of the score on Trial 1; this equalized the stimulus-figures for initial difficulty. Such curves for the group test are quite similar in shape. The curves for the individual test, based on a less normal group, fit the same shape, but less closely. Judd and Cowling reported that "the most radical changes in the records occur in the first part of each series. . . . The number of lines in the pattern might have been increased and then the serious errors would have appeared through a larger part of the series."¹⁵ The

TABLE I
MEAN NUMBER OF ERRORS MADE ON EACH REPRODUCTION OF STIMULUS-
FIGURES A, B, C, X, Y, Z

Stimulus-figure	N	Score on Trial										Total Score
		1	2	3	4	5	6	7	8	9	10	
A	118	5.4	4.3	3.8	3.2	3.1	2.9	2.8				25.2
B	118	7.6	6.1	4.9	4.2	4.0	3.9	3.4	3.2	3.4	3.1	44.5
C	118	16.9	13.1	10.3	9.1	8.1	7.3	7.0	6.9	6.4	6.0	91.4
X	46	5.4	2.9	2.3	2.3	1.8	1.6	1.5	1.2			18.9
Y	46	9.3	7.4	6.4	5.5	5.1	4.6	4.3	4.2	3.8	3.8	53.1
Z	46	11.6	9.2	7.4	6.2	5.2	4.6	4.1	4.0	3.4	3.5	58.2

present data do not contradict their statement, in the literal sense, as the raw scores for Diagram C do remain constantly above those for Diagrams A and B. It appears, however, that the learning of more difficult stimulus-figures does not differ qualitatively from that for simple figures, insofar as these curves are representative. This is a more cautious version of Fehrer's conclusion that "the learning of complex forms follows laws holding for the simplest perceptions."¹⁶

(2) *The relation between abilities.* Intercorrelations among total scores on stimulus-figures A, B, and C were used to determine whether individual differences in ability are consistent from form to form. The intercorrelations were as follows: A with B, 0.43 ± 0.05 ; A with C, 0.39 ± 0.05 ; B with C, 0.58 ± 0.04 ; average, 0.47.

Q (quantitative) and L (linguistic) scores on the American Council Psychological Examination for High School Students, 1938 edition, were correlated with performance on the figures. The average correlation of A, B, and C with Q was -0.21 ; with L, -0.20 . Since a high score on any figure indicates poor performance, these

¹⁵ Judd and Cowling, *op. cit.*, 358.

¹⁶ E. V. Fehrer, An investigation of the learning of visually perceived forms, this JOURNAL, 47, 1935, 192.

negative correlations show that there is a slight positive relation between ability to learn forms and mental abilities measured by the psychological examination.

A factor analysis of the intercorrelations between A, B, C, Q, and L was employed. A bi-factor pattern was postulated, and the working assumption that Q and L each represents a group factor was made. The results of this analysis are shown in Table II.

If the general factor represents elements common to all five tests, it is reasonable to call the group factor 'form-learning ability' since it represents what A, B, and C have in common with each other but not with Q and L. The size of the specificity loadings indicates that, under the conditions of this test, mental ability and general form-learning ability have no more influence on S's performance than do other un-

TABLE II
FACTOR LOADINGS FOR FIVE VARIABLES

Variable	General factor	Group factor	Specificity
A	0.311	0.462	0.830
B	0.256	0.759	0.598
C	0.270	0.673	0.689
Q	0.735	—	0.678
L	0.716	—	0.698

identified factors. The specificity may represent variations in the testing situation, or may be related to specific characteristics of the figures themselves.

The relation of initial ability to final ability was derived by correlating the score on the first trial with the total score on the last two trials for each stimulus-figure. The average correlation of initial score with final score for the same figure is 0.29 ± 0.05 . This indicates that an individual's performance at the outset of a series of trials is only slightly prognostic of his final performance.

A drawing ability score was obtained from the copy of W which S drew during the group test. The correlations with total score on Diagrams X, Y, and Z, respectively, for 46 cases, were 0.36, 0.41, and 0.27. These correlations are high enough to suggest that a more reliable measure of copying ability could usefully predict quality of form learning. Actually, of course, the score on Diagram W represents S's attitude toward the experiment, his concentration, and carefulness, as well as perceptual and motor abilities.

(3) *Use of association and other cues.* The results of the post experimental interviews indicate clearly that association was not used by every S. This is in contrast to the opinions of Gibson¹⁷ and Kuhlmann¹⁸ that association is essential to learning. On diagram X, 24 Ss reported a total of 34 associations (16 different). On Y, 32 Ss used a total of 53 associations (27 different). On Z, 28 Ss used 47 associations (27 different). It appears that the number of associations is related to the difficulty of

¹⁷ J. J. Gibson, The reproduction of visually perceived forms, *J. Exper. Psychol.*, 12, 1929, 1-39.

¹⁸ Kuhlmann, *op. cit.*, 319.

the stimulus-figure, but further evidence from more stimulus-figures is needed to establish this conclusion. It may be that associations become more necessary when experimental conditions, such as shortness of exposure or immaturity of the Ss, make learning more difficult.¹⁹

The relation between number of associations reported and performance is slight; the product-moment correlation between total score on the individual test and number of associations is -0.13 ± 0.09 . To a very small extent, then, use of associations is correlated with superior performance.

The Ss were classified into two groups, one reporting use of verbal description during study, one reporting no verbalization. Reports were not dependable as to the exact amount used on each figure. In all, 26 of the 46 Ss reported some verbalization. Such descriptions as "down, over, around, up," or "straight, curved, straight" predominated. Geometrical terms and measures were also used. The mean total score of the verbalizing group on Diagrams X, Y, and Z was 129.2; that of the non-verbalizers, 162.0. The critical ratio of this difference, which favors the verbalizers, is 2.2. Verbalization was associated with superior linguistic ability; the bi-serial correlation with linguistics (L) is $+0.24 \pm 0.12$. The bi-serial correlation between number of associations and L is -0.17 ± 0.10 .

The Ss were also classified on the basis of their kinesthesia into three groups: no kinesthesia, conscious kinesthesia, and unconscious kinesthesia. The last-named group made observable tracing movements during study, but denied knowledge of them when interviewed. The frequencies in these groups, respectively, were 14, 28, and 4. The mean total scores of the groups on the individual test were 140.9, 163.1, and 134.5, respectively. The difference between the first two groups has a critical ratio of only 1.27.

The tetrachoric correlation between use of association and conscious kinesthesia is 0.26; between verbalization and conscious kinesthesia, -0.38 . There was no clear relation between use of association and verbalization.

(4) *Perceptual types.* Of the Ss, 16 used associations in the learning of all the stimulus-figures; these may be considered 'subjective' in behavior. Only 8 never used associations; these would be classified as 'objective.' The remaining Ss, 22 in number, reported associations only on some figures. The product-moment intercorrelations between the number

¹⁹ Cf. A. R. Granit, A study on the perception of form, *Brit. J. Psychol.*, 12, 1921, 232; and Gibson, *loc. cit.*

of associations made on each stimulus-figure are: X with Y, $+0.53 \pm 0.07$; X with Z, $+0.007 \pm 0.10$; and Y with Z, $+0.18 \pm 0.09$.²⁰ The persistency of 'type' was also tested by the tetrachoric correlations between type on different figures, with these results: X with Y, 0.89; X with Z, 0.40; Y with Z, 0.55. Use of associations appears more common with some Ss than others; this trait was somewhat consistent on all figures. Few Ss, however, were consistently 'objective' or 'subjective' throughout the test. It therefore appears less misleading to refer, not to 'type,' but to a 'tendency to form associations,' which is a trait to be conceived as a continuous variable, in contrast to the dichotomy previously employed in description. The intermediate positions on such a scale may be as characteristic of some Ss as are the extreme positions for others.

Wulf contrasted 'isolative' learners, who used geometric and verbal descriptions of the figure and studied it by parts, with 'comprehensive' learners, who studied the figure as a whole, and associated the complete figure with 'real' objects. In this study, no S could be found who certainly was 'comprehensive.' Only 3 Ss gave names to any figure as a whole; 2 of these also used verbal descriptions. This implies that the characteristics described by Wulf are not mutually exclusive. An attempt was made to classify each S as 'isolative' or 'comprehensive,' on the basis of the type of association used. The former group included those using verbal and geometric descriptions; the latter, those whose associations were 'real.' Only 4 Ss were clearly comprehensive; 21 were consistently isolative. Characteristics of both types were shown by 18 Ss. It therefore appears that Wulf's categories are not helpful as descriptions.

(5) *Eye movements during study.* The records of the eye movements of the Ss were analyzed by methods resembling those of other investigators.

(a) *Types of pattern.* The patterns of eye movement varied markedly from trial to trial and from S to S. Some similarities do exist which are best described in terms of types of pattern. Caution in discussing these data is necessary, as some resemblance can be imagined within almost any set of irregular patterns. It should also be noted that the types of pattern described are a convenient fiction, and that few records fit the described types exactly.

Of frequent occurrence was the *cross-study* pattern—a regular progression of fixation in either direction.²¹ The *forward cross-study*, in which the eyes move from left to right, is similar to the typical pattern used in reading. Seldom found in reading, but common here, is the *backward cross-study*, in which the eye makes

²⁰ Not corrected for use of broad categories.

²¹ This terminology for pattern types is that used by L. C. Gilbert, (An experimental investigation of eye movements in learning to spell words, *Psychol. Monog.* 43, 1932, (no. 196), 22 ff.). His descriptions of the eye movement patterns used while studying words (*ibid.*, 31-33) would apply verbatim to the patterns in this investigation.

successive leftward movements. This seldom occurred alone; most frequently, it followed a forward cross-study pattern. The cross-study is in contrast to the pattern in which large portions of time are spent in continuous study of one small area. This may be shown by one extremely long fixation or by a *concentration oscillation*.

An *adjustment regression* was usually shown by a long movement in either direction followed by a brief fixation and a subsequent short movement in the same direction. This is similar to the regression which follows an incomplete return sweep in reading. A special case of adjustment was common at the beginning of trials. Before the exposure of the stimulus-figure, *S* was fixating the right dot. When the figure appeared, *S* shifted his gaze leftward to some point near its center, made a short fixation, then again moved, usually leftward, to the part that he apparently wished to study. It appears from the present results that orientation takes place

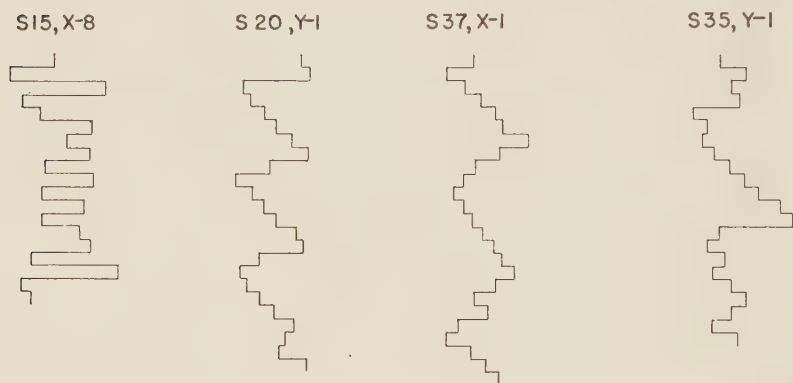


FIG. 3. SELECTED EYE MOVEMENT RECORDS OF FOUR LEARNERS

The captions at the head of the records give the *S*, the stimulus-figure, and the trial.

during the first fixation, and that the location of that fixation does not indicate the point which *S* wishes to study.

The *random oscillation* is a series of shifts of fixation between two or more widely separated points. This form occurs often in the records of *S* 15; one of the most striking examples is shown in Fig. 3. This rapid fluctuation implies an attempt to grasp the stimulus-figures as a whole, but may indicate merely that *S* was looking idly across the figure with little concentration. The random oscillation was also used for orientation. Many students showed three or four oscillations before commencing a cross-study or concentration pattern.

(b) *Patterns used on initial trials.* On the first trial of a series, the customary pattern showed one or more orientation fixations followed by a forward cross-study. This pattern was at times interrupted by a single backward movement, such as Gilbert calls the "pick-up" regression resulting from overreaching." After the forward cross-study, most *Ss* continued with a series of two or three more forward cross-studies. Others alternated forward and backward cross-study patterns. A third pattern was that in which the cross-study was followed by concentration on some point. Each of these types is illustrated in Fig. 3.

Other Ss showed less regularity. Some oscillated throughout the first trial. Many interrupted fairly regular cross-study patterns for brief concentration. During several trials on stimulus-figure X, S 34 studied with successive backward cross-studies. No forward cross-study was used on the first trial. This S was right-handed.

(c) *Patterns on later trials.* On trials other than the first of a series, little uniformity appeared. Many trials began with a cross-study, usually forward. Concentra-

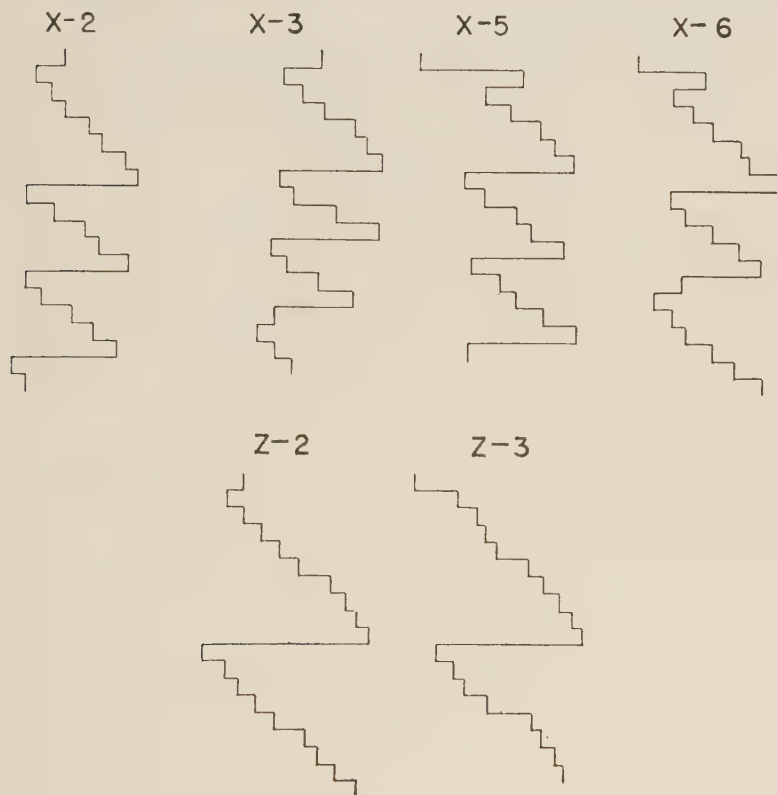


FIG. 4. EYE MOVEMENT RECORDS OF S46 ON SIX TRIALS
These results show close similarity of pattern.

tion patterns and slower cross-studies were then used. In other trials, concentration began at once, without cross-study. The following conclusions seem warranted by the results.²²

(i) Eye movement patterns were most regular on the first trials of a series.

²² The eye movement records of all Ss whose records were plottable have been microfilmed and deposited in the University of Chicago Libraries. See L. J. Cronbach, *Individual differences in learning to reproduce plane figures*, Univ. of Chicago, 1940 (unpublished thesis), appendix.

(ii) Regular forward cross-studies were used more on early trials than on later trials; on late trials, concentration on one area at a time was more common than continuous progression across the figure.

(iii) Cross-study patterns from left to right were more frequent than those from right to left, even though the conditions of the experiment forced *S* to make a leftward movement before his first study fixation.

(d) *Consistency of pattern within individual series.* Many *Ss* appeared to have a preference for one type of pattern, which they used on trial after trial. It is not feasible to demonstrate this fact statistically, and space does not permit presentation of many illustrative cases. The records of *S*46, a good learner, on 6 trials are shown in Fig. 4; the constancy of her pattern was greater than that of most *Ss*. Her pattern is unusually regular; many other *Ss* had patterns which were consistent but less regular in form. The resemblance between the study patterns of the same *S* on different trials and different figures is similar to that reported by Gilbert, who found resemblance between patterns when *S* studied the spelling of different words.²³

(e) *Duration of fixations.* The average duration of fixations on any trial (*TF*) was obtained by dividing the total time of study by the number of fixations made, including the first and last ones. The average duration throughout a series of trials on one stimulus-figure (*SF*) was computed by averaging the *TFs*. Series containing over three records not capable of being plotted were discarded in computing the *SFs*. The mean *SFs* for stimulus-figures X, Y, and Z were 15.71/30, 17.86/30, and 16.75/30 sec., respectively. The differences between X and Y, and Z and Y, are statistically significant; the difference between X and Z has a critical ratio of 1.9 (2.3 if mean *TFs* on all trials are averaged). The range of fixation-lengths also differed from stimulus-figure to stimulus-figure. The standard deviation (*SD*) of the *TFs* for the respective figures were 3.66, 5.44, and 4.32. All of the differences are significant. Since the means and variabilities change together, and since this change is not in the order of presentation, it is likely that characteristics of the stimulus-figures rather than of the situation are responsible for these variations.

Bartlett reported experiments with exposures of 1/15 to 1/4 sec. (2/30 to 7.5/30 sec.), and commented:

The brief controlled exposure may be regarded as an artificial and forced condition. This objection certainly holds good to some extent. But the ordinary glance of everyday life rarely rests for long on any given object; and further, when a person is definitely set to observe and reproduce, his keenness and criticism are as a rule considerably increased; so that in another sense the short exposure approximates most closely of all to normal conditions.²⁴

While it is not possible to compare the present conditions to those of everyday life, *S* was certainly set to observe and reproduce. In no case did any *S* have a *TF* below 8.9/30 sec.; very few individual fixations fell below 7/30. The average duration of fixations in general was far above Bartlett's estimate. Moreover, Buswell's *Ss*, looking at pictures, made fixations averaging 10.1/30 sec.²⁵ It appears that Bartlett's exposures were substantially shorter than the ordinary glance.

It was apparent in analyzing the records that some *Ss* tended to make consistently short fixations, while others tended to make frequent very long fixations. The consistency of individual differences in fixation-length is most readily shown

²³ Gilbert, *op. cit.*, 22.

²⁴ F. C. Bartlett, *Remembering*, 1932, 17.

²⁵ Buswell, *op. cit.*, 85 f.

by the correlation of the *SFs* from figure to figure. These were: X with Y, 0.600 ± 0.073 ; Y with Z, 0.515 ± 0.088 ; and X with Z, 0.394 ± 0.100 . A study of the average deviations of the *TFs* within a series also revealed a tendency for the *Ss* to be consistent within each series.

The mean *TF* on each trial was obtained by averaging the *TFs* for all the *Ss* whose records were capable of being plotted. These means are shown in Table III. The variation of the group on each trial was high, so that few of the differences from trial to trial are statistically significant. The consistency of the differences warrants the conclusion that there is an increase in the mean *TF* on the first 6 trials with each stimulus-figure. Although these trends seem to continue on trials after the sixth on Y and Z, the small number of cases available makes those averages unstable. The

TABLE III
AVERAGE DURATION OF FIXATIONS (*TF*) ON EACH TRIAL (1/30 SEC.)

Stimulus figure	Trial									
	1	2	3	4	5	6	7	8	9	10
X	13.6	15.0	15.1	15.7	16.5	16.6	16.6	16.2		
Y	14.9	18.1	17.2	16.5	18.6	17.7	18.0	17.3	20.2	21.1
Z	14.1	14.5	15.8	16.6	16.2	17.2	16.2	17.0	18.7	18.1

trend is less steady for Y than for X and Z; this appears to be due to a few exceptional *Ss* having very high individual *TFs* on two trials. Since the number of cases varied from trial to trial, a study was made of a sub-group for whom all records were usable; this confirmed the conclusion drawn from Table III.

With only three exceptions, the mean *TFs* on each trial increased in the order X to Z to Y. This is in accord with the *SFs* and supports the hypothesis that such differences are due to the nature of the stimulus-figures.

To determine the trend of fixation-length within trials, the sums of the first five, second five, and last five fixations on each trial were obtained. The average of each sum on all trials for each *S*, and the average for all the *Ss* on each trial were computed. These data supplement the previously established differences among the *SFs* and the *TFs* on the three stimulus-figures; it further appears that an increase from X to Z to Y occurred for fixations in all parts of the trials.

Differences between the sums for each stimulus-figure also existed. For every figure, the last fixations were greater than the second five, and these in turn were greater than the first five. The differences between the first and second five fixations, and between the second and last five, are not statistically significant by the usual test; critical ratios range from 0.6 to 2.3. The differences between the first and last five fixations are statistically significant for two figures (critical ratios: X, 3.0; Y, 3.6; and Z, 1.7). If the formula for the significance of differences of correlated variables had been employed, the critical ratios would have been increased. The consistency of these differences from stimulus-figure to stimulus-figure also enhances their validity. It is not true, however, that the sums increase from first five to second five to last five fixations on all trials; with few exceptions, the first sum was less than the last, but the second sum was at times as large as the last sum, and at times as small as the first. The first sum increased fairly regularly from trial to trial throughout the series; this tendency was less consistent for the other sums.

Whipple, who analyzed the introspections of learners, referred to a "'steady stare' or 'impression-of-the-whole' method which observers are prone to use at first."²⁶ The foregoing data consistently fail to indicate any such tendency. Steady fixations (stares) are far less common, at first, than cross-studies. Long fixations are most common on the later trials. While the cross-study may be used to obtain an impression of the whole, it is erroneous to say that it is characteristically used "at first"; its use is decreased, but not abandoned, on later trials.

(f) *Reversal ratios.* The use of regressions has previously been found to be a valuable index of the efficiency of eye movement patterns. In the present situation, it is incorrect to consider leftward eye movements as 'backward,' and the study of regressions is therefore not completely appropriate. A substitute index, the reversal ratio, has been defined. A reversal is any eye movement in a direction opposite to that of the preceding movement. The reversal ratio (RR) is defined by the equation: $RR = \text{number of reversals} \div (\text{number of fixations minus two})$. This index has a possible range from 0.00 to 1.00. The term may be illustrated by reference to Fig. 3: S15, on X-8, had an RR of 0.88; S20, on Y-1, of 0.33; S37, on X-1, of 0.30; and S35 on Y-1, of 0.60. It must be recognized that this function is arbitrary and crude, as the sampling of the numerator is so small that wide fluctuations are possible.

The series reversal ratios (SRRs) for each S were obtained by averaging his RRs on all trials for each figure. The SRR for most Ss was in the neighborhood of 0.50. The mean SRR for stimulus-figures X, Y, and Z were 0.4781, 0.4751, and 0.4467, respectively. The differences between X and Z, and Y and Z, may be considered significant (critical ratios: 3.1 and 2.7, respectively); the difference between X and Y has a critical ratio of only 0.4. Unlike the differences in fixation-length, these differences follow the order of presentation of the figures. It is, therefore, impossible at present to attribute them either to factors in the experimental situation or to characteristics of the figures.

Individual differences in RR and SRR were large. The range of RR on individual trials was from 0.08 to 0.88. The range of SRR was from 0.334 to 0.608. The correlations between SRRs on different stimulus-figures are positive and moderately large. For X and Y, the correlation is 0.69 ± 0.06 ; for Y and Z, 0.51 ± 0.09 ; and for X and Z, 0.57 ± 0.08 . The size of these correlations is especially significant in view of the coarseness of the terms forming the reversal ratio. These correlations are statistical evidence that the Ss tend to use similar eye movement patterns on different figures; those using many oscillations on one figure do so consistently, and vice versa.

An attempt was made to detect changes in the RR from trial to trial. The average RR for each trial was computed by averaging the RRs of all the Ss whose records for that trial were usable. These averages, shown in Table IV, yield no consistent differences or trends.

(g) *Location of fixations.* Records in which the location of fixations was uncertain, due to poor head records or poor pre-fixation of the dots on the wall, were discarded before the distribution of attention was analyzed. The width of the

²⁶ G. M. Whipple, The effect of practise upon the range of visual attention and of visual apprehension, *J. Educ. Psychol.*, 1, 1910, 262.

stimulus-figure was divided into 10 equal parts. From left to right, these were labelled, in order, *A, B, C, . . . J* (cf. Fig. 2). For every record, the fixations falling in each area were totalled, and the results converted into percentages by dividing by the total study-time. Fixations to the left of the marginal dot were grouped in Area *L*; fixations to the right of the right dot were grouped in Area *R*. The complete set of 12 concentration totals formed the concentration distribution.

The concentration distributions on various trials, and for different *Ss*, showed wide variety. Some were skewed to the right or left, showing that *S* had fixated one side of the stimulus-figure more than the other; some were quite peaked, showing that *S* had spent much of his time on one small area; others were rather flat, indicating a fairly even distribution of fixation. The group concentration distribution for each trial was obtained by averaging individual distributions. These values are

TABLE IV
AVERAGE REVERSAL RATIO ON EACH TRIAL FOR STIMULUS-FIGURES X, Y, AND Z

Stimulus-figure	Trial									
	1	2	3	4	5	6	7	8	9	10
X	0.444	0.466	0.458	0.498	0.517	0.446	0.495	0.493		
Y	0.465	0.468	0.452	0.503	0.488	0.499	0.502	0.454	0.509	0.421
Z	0.472	0.410	0.460	0.437	0.465	0.439	0.457	0.442	0.462	0.413

shown in Table V. There is apparently a consistent tendency to give greater attention to the left side of the figure. This is in accord with previous investigations.²⁷ The median position of fixation is within or very near to Area *E*, and the distribution is skewed to the left on each trial. It seems likely that the left end of *X* is less difficult than the right; certainly, it contains more straight lines, which Judd and Cowling showed to be easier than curves. It is less simple to estimate the difficulty of the halves of *Y* and *Z*. It is doubtful that the left is always most difficult; some force other than difficulty, perhaps habits from reading, is probably responsible for the preponderance of fixation on the left.

Each stimulus-figure has a distribution of distinctive form. That for *X* is uni-modal, that for *Y* is uni-modal and sharply peaked, and that for *Z* is like that for *X* on areas *A* to *D*, but has a 'saddle' in the middle and a secondary mode at *G* and *H*. That these distributions are characteristic of the stimulus-figures is implied by the consistent appearance of the distribution on every trial for the figure, with only trivial deviations. This consistency does not mean that the *Ss* individually look at the same points on trial after trial, but it does demonstrate the absence of any systematic shift of concentration from trial to trial for the group as a whole. The positions receiving greatest average attention on Trial 1 continue to do so on all trials.

The fact that the distributions are characteristic of the stimulus-figures implies

²⁷ K. M. Dallenbach, Position *vs.* intensity as a determinant of clearness, this JOURNAL, 34, 1923, 285; Ruth Burke and K. M. Dallenbach, Position *vs.* intensity as a determinant of attention of left handed observers, *ibid.*, 35, 1924, 267-268; C. L. Friedline and K. M. Dallenbach, Distance from point of fixation *vs.* intensity as a determinant of attention, *ibid.*, 41, 1929, 467; H. F. Brandt, Ocular patterns and their psychological implications, *ibid.*, 53, 1940, 266.

that some factor other than mere visual habit, or chance, is influential. The only other explanations that present themselves are that the differences arose from the experimental conditions or from the nature of the figures. The only variable element in the situation was the order of presentation; if this were influential, the distribu-

TABLE V
PERCENTAGE OF THE STUDY PERIOD WHICH THE GROUP USED IN FIXATION ON EACH TENTH OF THE STIMULUS-FIGURE

Stimulus-figure	Trial	No.	Area											
			L	A	B	C	D	E	F	G	H	I	J	R
X	1	27	1	2	7	15	16	12	12	12	11	10	2	1
	2	31	1	2	7	15	18	17	10	13	8	5	3	0
	3	29	0	2	9	12	18	14	14	12	10	6	2	1
	4	33	0	1	7	18	16	14	12	13	9	7	1	1
	5	24	0	1	6	17	16	16	11	12	10	9	3	0
	6	20	0	3	8	15	18	10	13	12	11	6	3	0
	7	17	0	0	7	13	14	14	11	13	10	12	4	1
	8	13	0	2	6	16	18	11	13	10	11	10	3	1
Mean			0	1	7	15	17	13.5	12	12	10	8	3	1
Y	1	29	0	6	14	14	13	22	11	7	9	4	1	0
	2	32	0	4	9	15	22	18	13	8	6	4	0	0
	3	33	1	3	10	18	16	21	11	10	7	2	1	0
	4	24	0	3	7	14	19	22	14	6	9	4	2	0
	5	27	0	3	8	14	18	22	13	8	8	5	0	0
	6	21	0	3	9	13	16	18	16	11	8	3	1	0
	7	17	0	5	9	12	16	20	13	9	5	7	2	0
	8	17	1	4	7	13	18	22	15	10	8	2	1	0
	9	16	1	5	9	10	14	19	20	11	5	2	2	2
	10	15	1	3	8	11	18	23	12	8	10	5	0	0
Mean			0	4	9	13	17	21	14	9	7.5	4	1	0
Z	1	30	1	3	7	16	20	10	7	7	11	10	6	3
	2	27	0	1	7	15	17	11	7	11	11	8	7	3
	3	29	1	2	7	15	16	12	8	11	13	7	7	0
	4	29	1	3	5	12	15	13	9	8	12	10	9	3
	5	26	1	2	6	12	20	11	11	8	10	8	7	3
	6	29	0	1	9	19	17	10	8	11	9	10	4	1
	7	24	0	3	6	13	17	10	11	10	10	10	5	4
	8	18	0	2	8	16	17	9	9	11	8	7	9	1
	9	16	0	2	12	19	18	8	6	13	12	5	3	2
	10	16	2	2	7	15	14	12	8	10	8	6	14	2
Mean			1	2	7	15	17	11	8	10	10	8	7	2

tions for X and Z would be expected to be least, rather than most, similar. Therefore this is ruled out as an explanation, and it becomes necessary to conclude that eye movements are determined by characteristics of the figure studied. This conclusion, while in agreement with Brandt's findings, contradicts the declaration of Guilford and Hackman that eye movements have little value as indicators of the attention values of stimuli.²⁸ These experimenters, however, appear to have based

²⁸ Guilford and Hackman, *op. cit.*, 383.

their conclusions on the direction of the first eye movement after the stimulus was exposed. It has been found, in the present study, that the first fixation apparently is often used for orientation; this would make it a poor indicator of *S*'s attention. While it appears likely, then, that eye movements are useful as indicators of the "attractiveness" of parts of the figure, further research is needed to determine whether eye movements are related to clearness. The present data do not indicate what characteristics of the figures determine the distribution of attention.

A measure of each *S*'s tendency to concentrate on each trial was obtained in a concentration quotient (*CQ*): the two adjacent tenths of the stimulus-figure given the greatest total attention were determined; the time spent on this fifth of the figure, divided by the total study time, gave the *CQ*. This function has a theoretical

TABLE VI

MEAN CONCENTRATION QUOTIENT ON EACH TRIAL AND MEAN SERIES CONCENTRATION QUOTIENT FOR EACH STIMULUS-FIGURE

Stimulus-figure	Trial										Mean SCQ
	1	2	3	4	5	6	7	8	9	10	
X	Mean	43.1	45.8	44.2	46.8	43.2	46.0	41.9	49.3		44.9
	No.	27	31	29	33	24	19	16	12		31
Y	Mean	44.2	51.7	52.2	51.8	50.6	50.0	50.6	51.9	49.7	53.8
	No.	30	33	32	24	27	21	17	17	16	15
Z	Mean	45.0	42.6	44.8	46.2	46.3	46.8	46.9	42.0	47.8	41.7
	No.	30	27	29	28	26	29	22	18	16	14

possible range from 0.20 to 1.00. Actually, the range found was from 0.26 (*S*31 on *Z*-1) to 0.98 (*S*36 on *Z*-10). The series concentration quotient (*SCQ*) for each *S* on each stimulus-figure was obtained by averaging the *CQ*s on all usable records. Table VI presents the mean *CQ* on each trial and the mean *SCQ* on each figure. The mean *SCQ* on Diagram Y was considerably greater than that for X or Z. This is in conformity with the group concentration distributions for these figures, for the distribution for Y was more peaked than the others. The differences between the mean *SCQ*s for X and Y, Z and Y, and X and Z were 2.6, 3.1, and 0.6 times their standard errors, respectively. Only the first two differences may be considered significant.

Both Judd and Cowling, and Tripp, reported that many *S*s sought the general shape of the figure on early trials, and on later trials attempted to learn specific details. Attention, they reported, was withdrawn from some parts of the figure and increased on others.²⁹ If this were true, one would expect the *CQ* to be relatively high for most *S*s on later trials. The actual data, in Table VI, show no tendency toward a steady increase in concentration. On Y, the mean *CQ* on Trial 1 is smaller than on any later trial. On X, there is a slight rise from Trial 1 to Trial 2. On Z, however, the mean on Trial 1 is greater than on Trials 2 or 3. On trials after the first, the mean *CQ*s are approximately equal. It may be concluded that for the group as a whole concentration—as defined by the *CQ*—did not increase substantially during the series, except in the case of the change from Y-1 to Y-2. Individual instances of increase in concentration from trial to trial were found, but such a phenomenon did not generally occur.

²⁹ Judd and Cowling, *op. cit.*, 356.

Unlike previously discussed measures of study tendencies, individual differences in *CQ* were not consistent from figure to figure. Correlations between *SCQs* on any two series are close to zero.

The center of concentration for each *S* was defined as the midpoint of the fifth of the figure receiving greatest attention on each trial. The distribution of centers of concentration of the group on each trial was in general similar to the concentration distribution, although narrower in spread. The distributions for different trials within the same series were similar. Two tendencies were noted which may be significant. On stimulus-figures *X* and *Y*, the distribution of centers of concentration on Trial 2 was slightly to the left of that on Trial 1. The distributions for *Z* show that few *Ss* concentrated on the right end of the figure on the first two trials, but that many concentrated on areas *GHIJK* on trials after the second.

Some of the foregoing data seem to support, and some to contradict, the finding of Judd and Cowling and Tripp that study on later trials is marked by increased concentration on some areas, and a withdrawal of attention from others. The mean fixation-length increases during the series, and concentration patterns appear most frequently on later trials. On the other hand, the distribution of attention for the group changes almost none from trial to trial, and the centers of concentration are distributed similarly on most trials. The *CQs* remain constant or fluctuate irregularly on trials after the first. This seeming contradiction may be reconciled by this interpretation of the previously accepted conclusion: on later trials there is a tendency for the *Ss* to concentrate for a longer *consecutive* period on one portion of the stimulus-figure, but this concentration may be followed or preceded by study of other portions of the figure. Whereas on early trials the time spent on any portion of the stimulus-figure may be scattered in small and widely spaced intervals, on later trials that time will tend to be spent on the area continuously.

(6) *Relation of eye movements to quality of performance.* In previous investigations, measurable differences between the eye movements of good and poor learners have been found.³⁰ Differences in the patterns of good and poor learners were much less striking in this investigation. It is true that the learner with the most regular patterns (*S46*) was among the best in performance, but the next most regular patterns were those of *S4* and *S7*, both poor learners. Each type of pattern was found for both good and poor learners. It does appear that poor learners used slightly more oscillations, either concentration or random, but this may be caused by poor learning on early trials. Possibly, too, good learners would demonstrate more oscillations if they attempted more trials than they needed for mastery.

The correlation between *SF* on each series and total score on that series is: for *X*, $+0.309 \pm 0.099$; for *Y*, $+0.103 \pm 0.109$; for *Z* $+0.235 \pm 0.103$. The correlations between *SRR* and performances are negligible in size. An attempt to compare the concentration distribution of a selected group of good learners with that of a

³⁰ Cf. Gilbert, *op. cit.*, 36-62.

group of poor learners revealed only trivial differences. The correlation of mean *SCQ* and score on each series is: for X, $+0.258 \pm 0.100$; for Y, $+0.074 \pm 0.106$; for Z, $+0.288 \pm 0.098$. It may be concluded that the eye movements of the good learners, as a group, do not differ markedly from the eye movements of the poor learners, as a group.

(7) *Relation of study methods to the reproductions.* Statistical generalizations are primarily useful when interpreted in the light of individual variations. Great caution must be employed in generalizing from case descriptions; certainly statements made about one *S* must not be considered typical of others. Limitations of space preclude a description of each *S*; one case is described below in great detail, to illustrate the method of analysis employed.³¹ Generalizations have been based on the analysis of all cases whose records were plottable.

S45 was outstanding in his performance on both the group and individual tests, requiring only a few trials on stimulus-figures X, Y, and Z. His introspections were more than usually voluble and seemed mature. He reported that he looked for the general shape of the figure and then looked specifically at definite points, and that he plotted in advance of study what he wished to look for. According to him, his study was affected by the directions; if he had known there were to be 10 trials to learn the figure, he would have divided the figure and studied by parts, but when told to learn as rapidly as possible, he did not use a part-study procedure. He claimed to have formed visual impressions most of the time, but also recalled the lines verbally as "straight, curved, straight, etc." He associated the left of X with the keel of a sailboat, or its rudder. (Model boat-building is his principal hobby.) On Y, he used the associations "mountains" for Area DEF and "clouds" for IJ; on Z, "two mountains" for the left end of the figure.

On X-1, he used a cross-study, then further cross-studies on the middle and right end. There was an apparent brief concentration pattern in Area DEF. Three atypically long fixations fell at H. The center of concentration was at DE. The reproduction was correct in general shape, although the angles were slightly inaccurate. The most serious error was at G. On X-2, attention on areas BC and E was reduced, while attention on G was greatly increased. The pattern as a whole was made of forward and backward cross-studies with no concentration pattern. The reproduction of Area G was nearly correct; the curve in DE was changed, but not improved; the angles in CD were improved. There was now no serious error. On X-3, most of the study period was occupied by a concentration pattern on FG. Fixations were generally quite short, which suggests either a tracing back and forth with the eyes or a scanning of the figure to find some point for concentration. In the reproduction, the proportion of the lines in FGH changed, but was over-corrected. On X-4, there was a long first fixation on D, then a cross-study with a long fixation at F. The remainder of the record was exclusively on EFGHI; no attention at all was given to ABC. The reproduction differed only slightly from that for Trial 3. (The records for Y and Z were treated similarly.)

³¹ The complete set of drawings made during the individual experiment has been deposited in the University of Chicago Libraries.

S seemed characteristically to recognize the point at which he had made an error in reproduction and to concentrate on that area in the next study period. He rarely concentrated at the start of the trial, but cross-studied until he reached a point of previous error, where he made a long fixation or a concentration oscillation. He frequently withdrew attention from a point previously learned, but this was in no case accompanied by a forgetting of the neglected part. When his concentration distributions were totalled for each figure and compared with those of the group, sharp differences appeared. On X, he concentrated much less on Area *ABCD*, which he reported naming with an association that was highly descriptive, for him. On Y his pattern was close to that for the group, but on Z he was much below the group in attention to *ABCD*; this area he also recalled by association. It appears that to some extent he may be able to substitute association for the concentration needed by others to learn some of the areas, but this hypothesis does not hold for Y.

The analyses of other good and poor learners failed to disclose clear and well-defined differences between successful and unsuccessful methods of study. Differences within each group were at least as great as differences between the groups. The influence of study pattern upon reproduction is not readily apparent. In general, improvement in reproduction most often followed a concentration oscillation on the part needing improvement. Improvements did occur which followed no corresponding concentration on the figure, and many concentration oscillations were not followed by corresponding improvements, but for most Ss, little improvement followed trials (after the first) which showed no concentration oscillation. Since improvement can occur without an increase of attention to the changed part and since attention alone at times does not bring improvement, it appears that the reproduction is not a dependable indication of the S's distribution of attention. Little dependence can be placed on such introspections regarding study methods as were obtained; they were frequently at variance with the objective photographic records.

The concentration oscillation seems to be characteristic of most superior learning. While many of the good learners concentrated at the point where their most serious error had occurred, many poor learners repeated an error for several trials before concentrating on that point during study, and some avoided concentration almost entirely. Among Ss who were more successful on some figures than others, concentration was most often present during study of the figure where performance was best. It cannot be concluded that concentration oscillations produce superior improvement; they may be only symptoms of the S's recognition of a point of error. Many poor learners failed to improve even after concentration; this suggests lack of some ability to retain which good learners possess. Some poor

learners appear to have had considerable difficulty in grasping the structure of the figure. This may be related to their lack of associations during study.

Many of the Ss of Judd and Cowling showed losses in accuracy from trial to trial. The experimenters ascribed some of these losses to withdrawal of attention from the part which deteriorated. In the present study, losses like these were found. A study of the eye-movement records preceding such losses showed that some losses were associated with withdrawals of attention, but not the majority of them. At times, losses occurred despite an actual increase in attention to the changed area. This implies that no single explanation is likely to be correct for all deterioration.

These findings do not invalidate the principal conclusion of Judd and Cowling—that learning of forms is gradual and quite complex. In fact, it is now demonstrated that the learning is even more complex than they stated. On the basis of their data, they accepted the hypothesis that the changes in a percept might be traced to S's distribution of attention. The present data show that this is frequently untrue, and that some further hypothesis is needed. No evidence is available to demonstrate why attention at one time brings improvement, and may at another time lead to no change, or even loss. Speculation suggests that mental set, motivation, and carefulness may be determining factors. It is possible that attention to a given line may fail to improve that line unless attention is given to its relation to the entire gestalt.

(8) *Drawing of the figures by parts.* Drawings by all Ss on each of the six stimulus-figures were classified as *whole* or *part*, depending on whether parts were missing. Among the 118 records on A, B, and C, 52 Ss made whole drawings on all trials. The remaining 66 drew incomplete reproductions on at least one trial. The number making one or more part drawings on each stimulus-figure is: A, 9; B, 18; and C, 60. Of the 46 Ss taking the individual test, 23 made whole drawings on all trials. The number making part drawings on each stimulus-figure is: X, 6; Y, 15; and Z, 16. The appearance of part drawings increased as the difficulty of the stimulus-figure grew. Figures Y and Z, of equal difficulty, were drawn by parts by the same number of Ss.

Of the 9 Ss making part drawings on A, 7 made them also on B or C, or both. Of the 18 Ss in the part group on B, 14 showed part drawings in the C series. Four of the 6 who made part drawings on X also did so on Z or Y, or both. It appears, therefore, that a person who makes part drawings on one figure is likely to do so on more difficult figures. The product-moment correlation, corrected for broad categories, between number of part drawings in the group and individual

tests is $+0.41 \pm 0.08$. The tetrachoric correlation, obtained by classifying each *S* as "all whole" or "occasionally part" on each test is $+0.20$. A third method of determining this relation is the product-moment correlation between the total number of trials showing part drawings on each test. This correlation, based on variables with a wider range than the others, is $+0.77 \pm 0.01$. Therefore, while *Ss* who make few part drawings may not show that tendency on other figures, those who make a comparatively large number of part drawings once may be expected to do so again.

In addition to the part drawings of the type described by Judd and Cowling, in which the left is mastered first and gradually augmented, many *Ss* in this study drew first the right, middle, or both ends of the figure, completing it later. Some figures seemed to lead to one type of learning more than others; thus drawing of the right was especially frequent on B, C, and X. The evidence as to whether individuals tend to learn the same part of the figure on each series is inconclusive.

Two hypotheses present themselves as interpretations of part drawings. They may indicate an attempt to learn the figure piecemeal, as Judd and Cowling supposed, or they may show that *S* tried unsuccessfully to grasp the figure as a whole. If the former explanation is correct, the part drawing should be preceded by a concentration eye movement pattern, with a higher *CQ* than usual. If the second is correct, one would expect the eye movements of those who draw only part of the figure to be no different from those of other *Ss*. An analysis of the records on the basis of these views was made for stimulus-figures X, Y, and Z. An unsuccessful attempt to learn the whole figure seems to have been responsible for drawing of only the left part by 3 *Ss* on Y and 3 on Z. A deliberate study of the left preceded drawing of the left for 2 *Ss* on Y and for the same 2 *Ss* on Z. Concentration on the left, following or combined with an attempt to study the whole, occurred for 3 *Ss* who made part drawings on Y; 2 of these, and one who had previously drawn the whole, used the same type of study before drawing the left on Z-1. Part learning is not clearly described by either hypothesis, then; some *Ss* seem to have employed a combination of the two previously mentioned alternatives. Among the few *Ss* who drew both ends of figure Y or Z, the evidence shows an apparent attempt to learn the whole in each case. Since neither hypothesis is correct for all *Ss*, it seems impossible to determine *S's* method of study from the fact that he makes part drawings.

The bi-serial correlation between the final score and use or non-use of part drawings for each figure was computed. These correlations, with their standard errors, are: for A, -0.12 ± 0.17 ; B, $+0.32 \pm 0.13$; C, $+0.10 \pm 0.11$; X, $+0.32 \pm 0.22$; Y, $+0.15 \pm 0.19$; and Z, $+0.13 \pm 0.19$. In general, then, part drawing is associated with poor final per-

formance, but these correlations are not statistically significant. Too few data are available to justify comparison of quality of performance of Ss using different types of study, but making part drawings.

DISCUSSION OF RESULTS

It is unjustifiable to generalize that the learning of figures of this type is similar to the learning of ink blots, of stimulus-figures made of several discrete units, or of meaningful forms. Caution is also necessary in interpreting the performance of these Ss as representative of that of persons of other ages.

The hypothesis was made, at the outset of the study, that the individual differences in form-learning ability are stable. This has been demonstrated to be in part false. The average intercorrelation of total scores on the three figures in the group test is only $+0.47$. Comparison of performances on the group and individual tests showed similarly low relations. The correlations of form-learning performance with the scores on the American Council Psychological Examination are even smaller. The correlation between the learning of form and ability to copy a figure directly is also low. It has been shown that individual differences in the learning of form cannot be entirely described by postulating a 'general mental ability' and a 'form-learning ability'; some other factors, apparently specific to each figure, are likely to influence S's performance greatly. Further investigation is needed to identify these other probable elements. The difficulty of predicting performance in form learning shows the complexity of the problem of predicting such behaviors as learning in shorthand and in artistic memory drawing, where form-learning is just one component.

Since individual differences fluctuate somewhat from figure to figure, one might expect the factors causing the differences between good and poor learners to be difficult to detect. Actually, no clearcut difference in learning methods appeared between good and poor learners. It was mentioned, above, that mental ability, as measured by the psychological examination, and ability to copy a figure are positively related to performance. The eye movement records of good learners disclose a tendency to concentrate on points of previous error more often than the records of poor learners. Use of association and use of verbalization are also associated with superior performance to some extent. The following are associated with inferior performance; use of kinesthetic devices, high average fixation length during study, high mean concentration quotients, and the making of part drawings. In view of the low relation between each of

these factors and performance, it is at present impossible to recommend any particular type of study as likely to be efficient. The case descriptions indicate that disabilities arise from different causes in various cases of poor learning. Further investigation is necessary to determine whether such disabilities can be remedied by training. It would also be desirable to determine what factors in an individual's development lead to such disabilities.

Many Ss have characteristic study methods which they employ on several figures. The eye movement patterns used by the same S on different trials and different figures often resemble each other. Individual differences in both mean fixation-length and mean reversal-ratio are moderately consistent from figure to figure. The tendency to form associations and to make part drawings are also somewhat stable. It is reasonable to suppose that each of these traits is either useful or undesirable as a method of study for most persons, even though this experiment has not detected clear relations between study method and quality of performance. A controlled experimental study, in which each S alternatively uses each method, might be planned to measure such relations. Since persons who use, or do not use, each method tend to do so consistently, it may then be possible to improve the learning of those who now employ poor methods, or who neglect to use good devices.

Previous investigators have not agreed whether all persons use naming, or association, in learning nonsense figures. The present study, based on a large number of Ss, shows that not all persons consciously use association on any one of the figures used. The use of association is increased on figures of greater difficulty. This may arise simply because difficult figures contain more lines and hence offer greater possibilities to the imagination; on the contrary, there is some evidence in this and other studies that association is increased whenever the conditions of learning become more difficult, making mnemonic devices more necessary. The evidence in this study contraverts the theory that learners can be divided into two exclusive types, either "objective" and "subjective," as Katz and others proposed, or "isolative" and "comprehensive," as Wulf proposed. It has been demonstrated that those who use associations do tend to do so consistently, and it is recommended that this trait be described by a continuous scale, rather than in terms of a dichotomy. Further investigation is needed to discover whether the persons who used no associations in this study might do so if the figures were made still more complex.

A major objective of this investigation was the validation of the con-

clusions of Judd and Cowling and Tripp, who attempted to infer the methods of study used by *S* from the reproductions made. The eye movement technique was used to record *S*'s actual method of study; this was compared with his reproduction to determine whether changes in the reproduction were directly related to the attention distribution. In general, such evidence supported the major conclusions of Judd and Cowling as to the complexity of form-learning and the general description of how a person improves his percept. Changes in the reproduction cannot, however, be related to shifts in attention in many cases, and the reproduction is therefore not a completely reliable indicator of the attention distribution. The statement of Judd and Cowling that losses usually are the results of withdrawals of attention from the changed portion is not borne out, in many instances, by the eye-movement records. One of Judd and Cowling's *Ss* consistently learned figures piecemeal, drawing only a part of the figure on the first trial, and adding to it on later trials. Whereas they inferred that this type of drawing indicates a deliberate study by parts, the eye movement records indicate that this is not so in all cases. Many cases of part drawing appear to arise, not from study of just one part, but from study of the whole accompanied by inability to retain the complete image. Further intensive investigation of this type of learning to determine the causes of this failure to retain would be desirable.

Since most previous investigators limited their studies to figures of uniform difficulty, in this investigation an attempt was made to determine the changes in learning method that accompany changes in the difficulty of the figures. Variations from figure to figure were found for most characteristics of the study method among the figures on the group test. Differences in the relative difficulty of figures are consistent on all trials of the series. More difficult figures lead to the use of more associations and to more part drawing. On the other hand, differences in fixation-length, reversal-ratio, and concentration-quotient are apparently not directly related to difficulty, even though the differences are probably related to some unidentified characteristics of the figures. The concentration-distribution during study is also apparently related to characteristics of the figure. Generalizations about changes from figure to figure are not highly valid, in the absence of evidence that the figures employed in this study are typical. So far as the present data are indicative, study methods used on figures of varied difficulty differ quantitatively, but not qualitatively. The evidence supports the hypothesis suggested by Fehrer, that the learning of complex forms is similar to that for simpler figures. It would be desirable to isolate

the characteristics of the figure which cause the changes in study method noted; such knowledge could only be determined by experimentation with a large number of figures of different forms and complexities.

Two findings have implications for the technique of further research. It was demonstrated that for the figures employed in this study, the equalized learning curves have very nearly the same shape. Therefore, for any group of *Ss*, if the learning curve for one figure is known, and the initial difficulty of another is known, the difficulty of the second figure at any trial after the first can be predicted. If this conclusion is substantiated by experiments with other figures and other *Ss*, it becomes possible to estimate the complexity of figures with increased accuracy. In the past, it has been necessary to determine complexity by such a technique as that of Fehrer, who presented each figure to every *S* for as many trials as were needed for mastery; the average number of trials needed for any figure gave a measure of its difficulty. The learning curves in this study suggest that one might estimate the complexity of figures by presenting them for one trial each, to a large group of *Ss*; the mean difficulty on this one trial would be a valid indication of final difficulty.

It has been demonstrated that the eye movement record is related to characteristics of the figure presented. Further studies, patterned after that of Guilford and Hackman, but making an allowance for orientation fixations, would be desirable to evaluate more thoroughly the eye movement technique for studies of attention.

In general, it may be concluded that the problem of the learning of form is exceedingly complicated. Between two individuals, some difference in study method may be expected. Such differences, which are a basic determiner of differences in quality of performance, must be investigated for each individual case before efficient remedial measures can be taken. The eye movement technique has apparent value in providing valid records of study methods and may provide a method for diagnosing the nature and causes of individual differences.

